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Gun-Fired Precision Munitions for the Transformed Army

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Gun-Fired Precision Munitions for the Transformed Army

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PREFACE

This document was prepared for the Deputy Under Secretary of Defense for Science and Technology (DUSD(S&T)) under the “Precision-Guided Mortar Munitions” task. Technical cognizance of this task is assigned to Mr. Jack Taylor.

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GUN-FIRED PRECISION MUNITIONS FOR THE TRANSFORMED ARMY

A. INTRODUCTION

Repeated attempts to develop gun-fired precision munitions attest to the attractiveness of these munitions, but the lack of success of these attempts also attests to the difficulty of moving them from the laboratory to the field. The appeal of these munitions has grown because of the emphasis on Army Transformation. Many of the development difficulties—underestimating the time required for research and development (R&D), program funding instability, or a general focus on one aspect of the cost-schedule-performance triad to the detriment of the other two—had more to do with management than with technology.

On the other hand, even the failed programs, when taken together, have demonstrated that the technology needed for gun-fired precision munitions is viable and ready for exploitation. Recent advances in computer modeling, miniaturization, and design increase the likelihood of success if these advances are combined with some of the added flexibility afforded by new Department of Defense (DoD) acquisition policies.

In this paper, we summarize the advantages of gun-fired precision munitions and show that developing and fielding these munitions is now technically feasible. We also show that changes in the approach to acquisition (i.e., changes based on the best commercial practices) improve the prospect that a program will successfully include feasible innovations. An important aspect of the successful acquisition of precision munitions includes an event-driven rather than a schedule-driven R&D program. We illustrate the potential pitfalls by comparing the Joint Direct Attack Munition (JDAM)[1] and the Sense and Destroy Armor (SADARM).[2]

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1 JDAM is a Global Positioning System (GPS)-guided bomb.

2 SADARM is a 155-mm cannon-fired “dumb” projectile that contains two smart submunitions.

B. WHY GUN-FIRED PRECISION MUNITIONS?

The Army is redefining its role by transforming to a lighter, more flexible force. A vital component of the transformation process is to lighten the logistics burden by using precision munitions. Gun-fired precision munitions would have a huge impact on the logistics tail, if only because gun-fired munitions comprise a large fraction of the weight that the forces carry. The Army has recognized this need for precision, for example, by funding precision-guided mortar munitions but has postponed its program to develop the gun-fired precision munitions planned for Future Combat Systems (FCS).[3]

Potential adversaries are reacting to these initiatives, and future opponents will include dispersed or fast-moving forces as well as heavy, slow-moving massed forces. The Army's new concepts of operations will need to include methods to engage dispersed or isolated targets and moving and stationary targets, and precision munitions offer the commander additional flexibility in the rapidly changing battlefield environment. In addition, policies of avoiding collateral damage are unlikely to change, and precision munitions further these policies.

Gun-fired precision munitions offer added advantages to the Objective Force.[4] For a given range, gun-fired precision munitions would be inherently the most accurate and lightest of all the possible smart warheads. This lightens not only the logistics burden, but also the burden imposed on any command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR) system. In addition, such munitions would provide added flexibility for ground commanders: the inherent speed and responsiveness of a gun-fired precision munition would enable increased tempo and increased choices.

Such weapons also allow the commander new employment concepts. The effectiveness of the Special Forces and the Air Force in Afghanistan was inspired by new ways of thinking but also required the existence of a precision munition (e.g., JDAM). The conflict in Afghanistan has demonstrated the transformational properties of precision munitions and these new ways of thinking.

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3 The Army has postponed development of the Multi-Role Armament and Ammunition System (MRAAS) gun-fired precision munition because of the delay in the MRAAS cannon. Thus, the Army has not vigorously pursued gun-fired precision munitions with terminal seekers since SADARM. [To reduce the circular error probable (CEP), Excalibur used GPS guidance rather than terminal guidance.]

4 See Internet website http://www.objectiveforce.army.mil/.

Army leadership and the Office of the Secretary of Defense (OSD) have supported and encouraged the development of precision munitions for a long time. In 2001, the Army white paper, *Concepts for the Objective Force*, stated that

> Operations [of the Objective Force] will be characterized by developing situations out of contact; maneuvering to positions of advantage; engaging enemy forces beyond the range of their weapons; *destroying them with precision fires*; and, as required, by tactical assault at times and places of our choosing.[5] [Emphasis added]

As recently as May 2002, Deputy Secretary of Defense Paul Wolfowitz said that

> We want Army weapons systems to support a transformed Army that is more mobile, lethal, and deployable across a wide range of future contingencies. *Precision fire has proved to be one of the most transformational improvements in modern warfare*. . . . We must invest in innovative technologies and ideas that represent the future of battlefield technology for indirect fire.[6] [Emphasis added]

Thus, to ensure success in the Army of the future, the Army of the present must vigorously pursue the development, procurement, and fielding of precision munitions.

C. TECHNOLOGY FOR GUN-FIRED PRECISION MUNITIONS

The technologies needed for building and targeting gun-fired precision munitions exist today. During the past 20 years, dramatic technological improvements have taken place, not only in individual technologies, but also in software and development techniques. These new technologies can be used to build unprecedented lethal and precise indirect-fire munitions. The Army is simultaneously building and developing much of the C4ISR infrastructure to support indirect fires[7] and should take advantage of this infrastructure to build gun-fired precision munitions.

Proven technologies (and completed subsystems) for precision munitions include

- GPS for circular error probable (CEP) reduction
- Gun-hardened seekers and laser detection and ranging (LADAR) for true precision in the terminal guidance

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5 *Concepts for the Objective Force,* United States Army White Paper, 2001, p. 6.

6 Deputy Secretary of Defense Paul Wolfowitz, Pentagon News Briefing, 8 May 2002.

7 For instance, the Army is pursuing Missiles-in-a-Box (formerly Netfires) and the Common Missile, both of which will use targeting information from Joint and Army systems. This information could also be used to target gun-launched indirect-fire munitions.

- Gun-hardened electronics [e.g., field programmable gate arrays (FPGAs) and digital signal processors (DSPs)]
- Radios/radars
- Warhead/fuse technology (e.g., target-adaptable shaped charge and explosively forward penetration lethality mechanisms).

Although this list is by no means complete, it does illustrate the existence of technological solutions to the challenges found in the firing chain. GPS and seekers enable precise guidance for fixed and moving targets. Electronics enable the "smarts" in the precision munition (i.e., the ability to hit a wider variety of targets under a variety of conditions). Radios and communication devices that provide in-flight updates enable even more precision and accuracy and diversity of targets because the munition can rely on outside information for in-flight updates. Improvements in warhead and fuse technologies have created smaller but more lethal warheads, which reduces the munition footprint and weight. Each of these important technologies has been proven in gun-fired (high-g) environments, either in fielded munitions (e.g., Copperhead)[8] or in cancelled development programs (e.g., SADARM).

We now have a deeper understanding of software and control within precision munitions. The technology has benefited from a variety of sources, including missiles [e.g., tube-launched, optically-tracked wire-guided missile (TOW), Multiple-Launch Rocket System (MLRS)] and other smart munitions [e.g., Brilliant Anti-Armor Technology (BAT)]. From these and other programs, we have learned how to write guidance, navigation, and control (GN&C) software and about realistic automatic target recognition (ATR) capabilities. In addition, the blurring lines between digital hardware and software for signal processing (e.g., the use of FPGAs) have revolutionized processing speed and allowed the use of huge, on-board databases that the munition can access to make in-flight corrections. The Army can use this rich experience base to create software and control for gun-fired precision munitions.

Development and design techniques, in general, have also improved dramatically. Clearly, the improvements in computers and modeling theory have enabled previously unimagined advances in modeling complex systems, including the design of precision munitions. In particular, the models of the high-g structural analysis, which have a direct impact on gun-fired munition design, have improved. The experiences of developing these

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8 Copperhead is a 155-mm cannon-launched, laser-guided projectile.

munitions (particularly, the failures such as SADARM) have emphasized the importance of early testing and the need for program flexibility to respond to uncovered problems. These lessons have been learned in several programs, including successful ones such as JDAM.

Table 1 lists some of the technological advancements made since the 1980s that have an impact on the chances for a successful gun-fired precision munitions program. These changes mean that fewer design cycles will be needed and what needs to be redesigned will be better understood. That is, knowledge gained from successes and failures can be obtained from a combination of embedded instrumentation and robust computer modeling, which means that cycle time for a redesign would be shortened substantially. Finally, the Army has built an in-house, high-g structural design capability to guide developments. The Army is now positioned to take advantage of these lessons and developments.

Table 1. Technology Comparisons

1980s	Now	Impact
Limited high-g experience with electronics	Extensive experience from STAFF, X-ROD, SADARM	Fewer redesigns needed
Limited/no computer modeling	Extensive computer modeling	• For a given capability, few redesigns needed • More complex munition design possible
Limited on-board instrumentation and telemetry	Miniaturization, Hardened Subminiature Telemetry and Sensor System (HSTSS), improved on-board instrumentation and telemetry	Potential for detailed diagnostics from successful and failed shots
Application-specific integrated circuits (ASCIs)	FPGAs	Cycle time on redesign reduced from ~ 18 months to ~ 3 months

Notes for Table 1:

STAFF was a program to develop a 120-mm smart, top-attack, fire-and-forget tank round that searched out and destroyed enemy armor using an explosively formed penetrator at distances beyond the reach of today's conventional tank munitions.

The X-ROD program was structured to demonstrate a fire-and-forget, guided, boosted, and "smart" tank-fired kinetic energy (KE) projectile for highly accurate defeat of current and projected armor threats at ranges of at least 4 km.

D. DEVELOPMENT AND PROCUREMENT OF GUN-FIRED PRECISION MUNITIONS

In the previous section, we reviewed recent progress in technology. In this section, we will consider the emerging changes in management approach that have been gaining favor over the past few years. We will look at these changes in the context of how they will enable or impede the development of precision munitions.

Exploiting previous lessons and new developments will take place within the context of an acquisition program. The detailed regulations for acquisition programs are routinely modified. In fact, as of this writing, these regulations are in the process of being canceled; however, they will be reissued in a less prescriptive form that fosters efficiency, creativity, and innovation.

One of the ideas receiving increased emphasis is ensuring the adequate maturity of the technologies that will be used in DoD programs. This emphasis is reflected in the Government Accounting Office (GAO) work on best practices by industry and DoD,[9] in the separation of technology development and product development in the most recent 5000 series of documents, and in the insistence on technology risk reduction during Concept and Technology Development (CTD) in drafts of the new streamlined 5000 series of documents. These efforts are aimed at reproducing private industry's best practices, which include separating the creative yet risky realm of ideas and inventions from the mechanized and precise world of product engineering and development.

One way to ensure technical maturity is to structure new programs so that they only insert technologies that are already mature. This approach reduces risk but sacrifices innovation. In particular, it forecloses the possibility of inserting technology required to effect transformations driven by changes in concepts of operations or other nonmateriel areas.

If a program wants to introduce new technologies driven by formal "Requirements" or by the need for transformation and also have a predictable System Development and Demonstration (SDD) phase in terms of cost and duration, the somewhat unpredictable innovation must be introduced in the CTD phase, which occurs between Milestones A and B. This CTD phase must be event-driven rather than schedule-driven if the new

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[9] GAO/NSIAD-99-162, *Best Practices: Better Management of Technology Development Can Improve Weapon System Outcomes*. United States General Accounting Office (GAO) Report to the Chairman and Ranking Minority Member, Subcommittee on Readiness and Management Support, Committee on Armed Services, U.S. Senate, July 1999 (see Internet website http://www.fas.org/man/gao/nsiad-99-162.htm).

technologies are to be sufficiently mature before entering product development. In other words, an event-driven CTD phase is a *prerequisite* for a schedule-driven SDD phase. In general, an event-driven innovation phase that matures the innovative technologies is also the only way to produce the understanding of these new technologies, which is a prerequisite for cost and schedule realism in later phases.

In addition to completing technology maturation before entering engineering and production, the acquisition community has been moving toward a spiral approach to development.[10] By deferring those technologies that are not at the proper maturity level, the Army can ensure that a useable (yet upgradeable) smart munition can be fielded sooner rather than later. The spiral approach also allows program managers (PMs) to achieve a workable balance among cost, performance, and schedule drivers. In the past, smart munitions programs have failed because of an overemphasis on one aspect of the cost-schedule-performance triad to the detriment of the other two.[11]

To recapitulate, the increased emphasis on ensuring technical maturity, if implemented in particular programs, will improve the prospects of successfully fielding smart munitions. In such systems, many technologies need to be ready at the same time, and spiral development offers the possibility of successfully fielding a partial capability while waiting for the upgrades to mature. However, this spiral approach also has a downside: if technology development schedules are too inflexible, PMs will be forced to abandon genuine technology development and rely on what is available or to embrace a level of risk that precludes cost and schedule realism.

E. BUILDING A GUN-FIRED SMART MUNITION TODAY

Gun-fired precision munitions will not be as inexpensive as dumb bullets. However, the department can control cost (and schedule) by inserting new technologies in block improvements. Proving technologies for block insertion *before* entering production can mitigate risk, once again aiding the PM's efforts to control costs. This block approach (spiral development) is appropriate for most innovation and technology development when the

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[10] Spiral development is an iterative, cyclical process of build-test-fix-test-deploy. Each release builds on the lessons of the previous release. There can be several releases during the acquisition and deployment of a system or system block.

[11] For example, the SADARM program suffered from an overemphasis on an accelerated schedule. Efforts to work around a design known to be flawed continued for 10 years because the program never had the 18 months (estimated by some) needed to do the redesign.

innovation is a step-by-step process and does not require the simultaneous maturation of several technologies at once.[12]

To have an effective precision engagement munitions program, the Army must ensure sufficient financial support. In the past, the views of munitions cost have focused on the R&D expenditure rate, total procurement cost, and unit cost. This focus is seemingly reasonable; yet, historically, munition development programs have been beset by a lack of funding and unrealistic schedule and cost goals.

Often, munitions do not go through enough design cycles or enough testing in the "risk-reduction" phase [what used to be called the Preliminary Design and Risk Reduction (PDRR) phase], and PMs are attempting to turn technologically immature munitions into products. The munition designers, who should be focused on performance, are focused instead on meeting schedules or reducing unit costs. This increases the risk that the munitions program will fail because the focus is diverted from performance too early in the program. The focus should be on schedule and cost *only* when the individual technologies have been proven.

Once the performance is satisfactory and the focus shifts appropriately to production, the estimated unit costs need to be large enough so that the programmed procurement budget is realistic. Precision munitions may be needed in smaller numbers than "dumb" rounds, but significant numbers are still needed if the munition is to be a "standard" part of the commander's tool kit. A sufficient number of precision munition rounds are needed to support training and to be a realistic alternative choice for the commander in the field. For example, Copperhead had an optimistic unit-cost projection, based on a large total procurement. However, when the unit cost came in higher than expected, the size of the buy was decreased, and this, in turn, increased unit costs. Even though Copperhead had technical problems that restricted its utility, the small numbers of munitions precluded necessary training and thwarted the potential utility of the round.

An interesting benchmark against which to measure these programs is JDAM.[13] The R&D and integration tasks are simpler than those that would occur in most indirect-fire

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12 As contrasted, perhaps, with the technological demands for building the nuclear bomb or for implementing the Navy's Cooperative Engagement Capability (CEC).

13 JDAM is a guidance tail kit that converts existing unguided free-fall bombs into accurate, adverse weather "smart" munitions. It uses either the 2,000-pound Bomb Live Unit (BLU)-109/MK 84 warhead as the payload. Guidance is facilitated through a tail control system and a GPS-aided Inertial Navigation System (INS).

smart munition programs and much simpler than those for a munition that has on-board seekers. Nevertheless, because attempts were made to accelerate this program between Milestones I and II (leading the developers to skip some of the early risk-reduction testing), program delays occurred later in the development. Specifically, in October 1993, the system passed Milestone I and entered into a planned 18-month Demonstration/Validation (DEM/VAL) source-selection phase. One year later, however (in the fall of 1994), the program was accelerated 18 months to try to get precision munitions into the field as soon as possible. This led to small buys [low rate initial productions (LRIPs)] of systems in 1997 and 1998, but these systems were clearly not completely satisfactory because Milestone III was delayed to allow for a third LRIP buy. The program was delayed once more when Milestone III was postponed again so that a fourth LRIP buy could be made and the munition could be tested. Thus, this early decision to accelerate the R&D by 18 months actually turned the program into a block upgrade approach and almost certainly delayed fielding—at least in the full set of aircraft platforms.

In contrast, the SADARM program was a new-start, cannon-fired 155-mm munition. It was a precision munition that used a millimeter wave/infrared (MMW/IR) sensor suite. A parachute was used to slow the submunition's descent and enable the MMW/IR sensor to scan to acquire targets and fire an explosively formed penetrator. It was, therefore, a much more technically difficult project than JDAM.

Despite our view that the attempted acceleration of the JDAM program was overly ambitious, this program has been very successful. This success can be attributed, in part, to adequate resources. Contrasting the JDAM and SADARM funding streams provides an interesting perspective. Looking at the cumulative R&D funding (see Figure 1) and bearing in mind that the SADARM was a more technically challenging program (especially given the sensor integration required), it is not surprising that SADARM struggled with the funding it received. A look at the year-to-year funding (see Figure 2) sheds additional light. The SADARM funding stream is approximately constant (not growing) in the early years, which is indicative of the program's stagnation. In addition, SADARM was a complete projectile development, and JDAM did not have to develop the bomb/defeat mechanism. Also worth noting is that the estimated costs of the JDAM kit in 2001 were above $20,000 each for a nearly 100,000-unit buy. For the first examples of a new type of precision munition, a program will generally have to pay a lot for each unit of a large buy if the munitions are to be integrated successfully into the force.

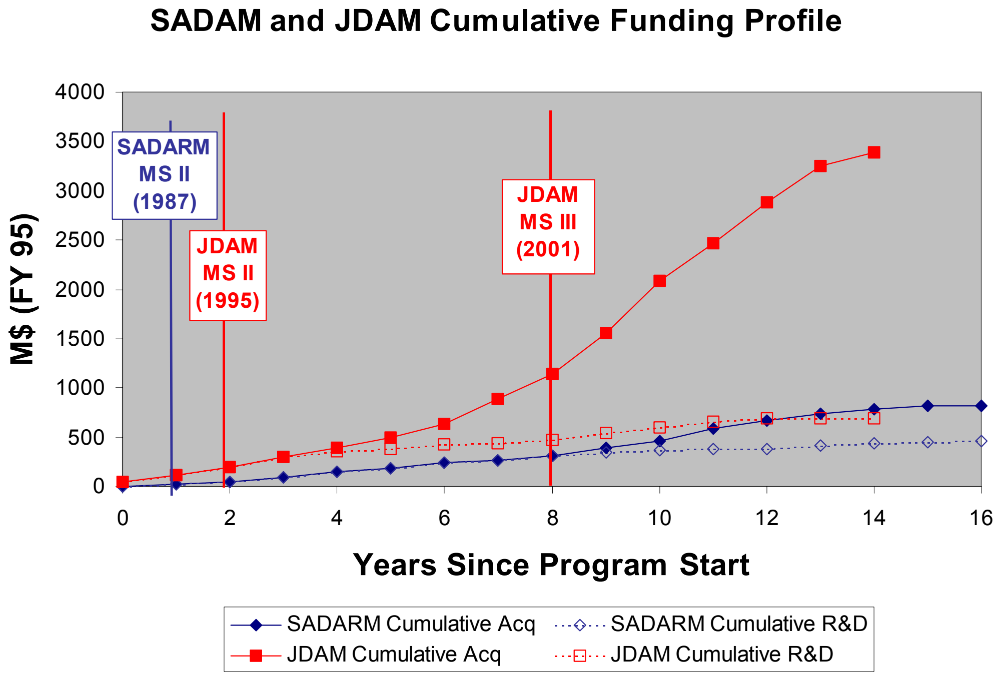

Figure 1. Yearly Funding vs. Start Year of SADARM (1986) and JDAM (1993) in 1995 Dollars

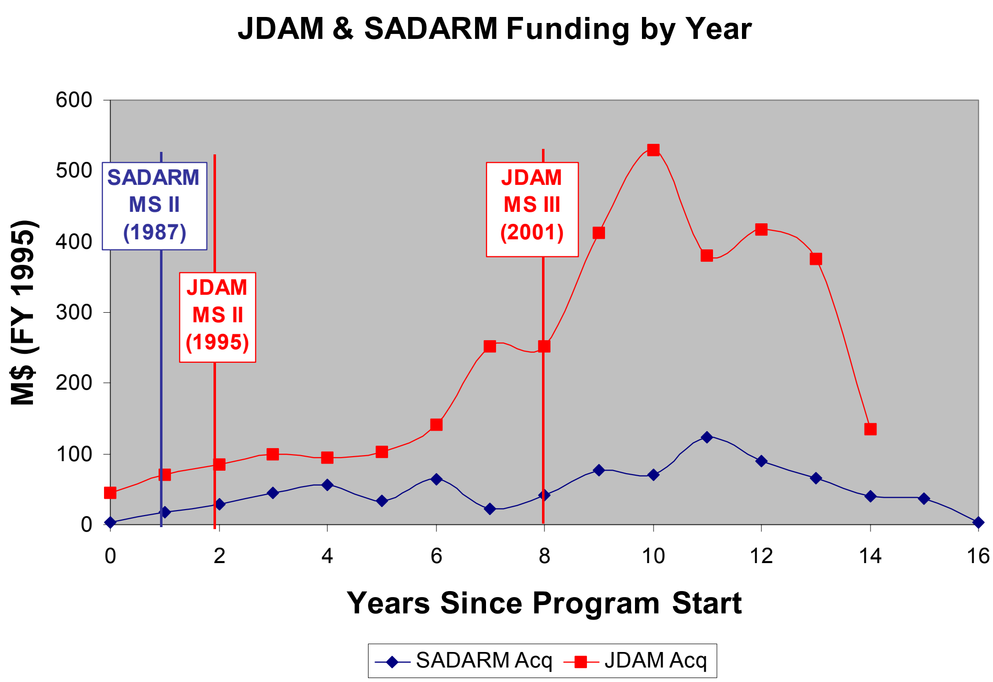

Figure 2. Funding Profile vs. Start Year of SADARM (1986) and JDAM (1993) in 1995 Dollars

Schedule issues also have an effect on the differing outcomes of the two programs. SADARM did not have a true Milestone I, so the In-Process Review (IPR) is shown for reference. Between this IPR and what we have called Milestone II was a period of about 14 months, which left little time for redesign and technology insertion. On the other hand, JDAM had about 24 months between Milestone I and Milestone II. The relative ease of the JDAM program and the de facto block approach allowed it to fix aircraft specificity problems and insert new technology. In addition, note that JDAM had a rather smooth ramp-up from R&D money to procurement dollars, whereas SADARM did not (especially in the years 1991 to 1995, shown as years 5 to 9 in the figures). This meant that JDAM, unlike SADARM, had a predictable funding profile, and this enabled the developers to concentrate on meeting the schedule. Even so, JDAM was late in availability to some platforms. However, the program was never canceled and has been extraordinarily successful.

F. SUMMARY

So, what would a successful gun-fired smart munitions program look like? It would use a block approach, based on delivering the "smarts" the user wanted (but initially only in amounts that the developer could provide fairly quickly). As soon as possible after Milestone A, the program developers would be aggressively test-firing instrumented rounds with complete subsystems. The schedule leading up to initial Milestone B would be event-driven and therefore flexible. The "pre-planning" part of what used to be called Pre-Planned Product Improvement (P3I) would be scheduled and budgeted in the CTD phase. In a block approach of this type, before the delivery of the first block, time must be taken to ensure that future developments are not inadvertently forestalled. Further technology development would proceed in parallel with the product development in SDD.

Given the rapidly changing environments in which the Army will operate, the potential benefits of indirect-fire precision munitions seem clear, and the Army and DoD leadership have articulated and supported precision fire as a key element of transformation. Hints of the future success of such a weapon are evident in the recent successes, from *Desert Storm* to *Operation Anaconda*.

The technical capability exists to develop and field gun-launched indirect-fire precision munitions that could engage moving targets out to 20 km or beyond. Successful development depends primarily upon adequate time and resources. Adequate time to solve unanticipated problems is especially important in the CTD phase of a program. In fact, the

CTD phase should be mostly event-driven, with the recognition that additional funds, while they can reduce risk, cannot generally accelerate this phase of a program.

The new acquisition approach, with its emphasis on complete technology development before product development, increases the probability that these programs will be successful, provided that the CTD phase has sufficient schedule flexibility. For a successfully developed munition to become a useful part of the inventory, the unit production costs must be realistic, and instrumentation must be embedded to isolate problems and facilitate upgrades. Finally, adequate quantities of the munition should be programmed to support training and flexibility for the commander in the field.

GLOSSARY

ASCI	application-specific integrated circuit
ATR	automatic target recognition
BAT	Brilliant Anti-Armor Technology
BLU	Bomb Live Unit
C4ISR	command, control, communications, computers, intelligence, surveillance, and reconnaissance
CEC	Cooperative Engagement Capability
CEP	circular error probable
CTD	Concept and Technology Development
DEM/VAL	Demonstration/Validation
DoD	Department of Defense
DSP	digital signal processor
DUSD(S&T)	Deputy Under Secretary of Defense for Science and Technology
FCS	Future Combat Systems
FPGA	field programmable gate array
GAO	Government Accounting Office
GN&C	guidance, navigation, and control
GPS	Global Positioning System
HSTSS	Hardened Subminiature Telemetry and Sensor System
IDA	Institute for Defense Analyses
INS	Inertial Navigation System
IPR	In-Process Review

JDAM	Joint Direct Attack Munition
KE	kinetic energy
LADAR	laser detection and ranging
LRIP	low rate initial production
MLRS	Multiple-Launch Rocket System
MMW/IR	millimeter wave/infrared
MRASS	Multi-Role Armament and Ammunition System
NSIAD	National Security and International Affairs Division (GAO)
OSD	Office of the Secretary of Defense
P3I	Pre-Planned Product Improvement
PDRR	Preliminary Design and Risk Reduction
PM	program manager
R&D	research and development
SADARM	Sense and Destroy Armor
SDD	System Development and Demonstration
TOW	tube-launched, optically-tracked wire-guided missile

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14. ABSTRACT

In this paper, we proposed that now is the time for the Army to develop a full suite of gun-fired precision munitions. We summarize the advantages of gun-fired precision munitions and show that developing and fielding these munitions is now technically feasible. We also show that changes in the approach to acquisition (i.e., changes based on the Best Commercial Practices) improve the prospect that a program will successfully include feasible innovations. An important aspect of the successful acquisition of precision munitions includes an event-driven rather than a schedule-driven R&D program. We illustrate the potential pitfalls by comparing the Joint Direct Attack Munition (JDAM) and the Sense and Destroy Armor (SADARM).

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